

MESOSCALE MODEL SIMULATIONS OF COASTAL FOG

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LONG TERM GOALS

We wish to understand the factors governing the formation of coastal fog, especially its horizontal variability and relationship of variations to flow interaction with coastal topography.

OBJECTIVES

We wish to obtain successful simulations of the onset, variability (on scales of tens of kilometers) and dissipation of coastal fog using a nonhydrostatic mesoscale model.

APPROACH

The treatment of cloud formation in mesoscale models is mainly suited for larger-scale, layered cloud formation. The process is sometimes referred to as "all or nothing", meaning that a given grid cell is either saturated or unsaturated. When dealing with fog, which is often patchy in nature, especially in its formative stages, this assumption tends to produce unrealistic results. Part of the lack of accurate fog prediction stems from inadequate treatment of cloud physics and radiation. Part of it results from unsophisticated treatments of mixing within the planetary boundary layer.

Recently, planetary boundary layer (PBL) schemes featuring closure assumptions higher than first order have been implemented into mesoscale models (Burk and Thompson 1989; Gayno 1994). These schemes predict turbulent kinetic energy, and therefore can predict the effective eddy viscosity. This represents an improvement over the simpler schemes which are forced to prescribe viscosity as a function of grid scale variables.

The second noteworthy advance is the development of a module designed to predict liquid water arising from fog formation, which may occur in a grid cell which is, on average, subsaturated (Gayno 1994). The amount of cloud water is diagnosed based on variance of supersaturation within a grid cell, which in turn depends upon the level of turbulence in the grid cell. Because liquid water can exist in a subsaturated grid cell, the onset of fog, especially concerning its effects

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on radiation, can occur more gradually than is possible in the "all or nothing" scenario. This adds more realism to numerical prediction of fog, and gives us the tool to study the effect of mesoscale flow variations on fog formation. Heretofore, most numerical simulations of fog formation have relied on either one-dimensional microphysical models, or large-eddy simulations, in which no account could be taken of effects such as terrain or other mesoscale variability.

Because offshore data are limited, part of this study focuses on quasi-idealized simulations of fog formation in two and three dimensions, in which we prescribe the initial conditions, but allow the flow to interact with realistic topography as it reaches the coastline. Initially, in two-dimensional simulations representing a vertical slice of the atmosphere, we prescribe a gradient of sea surface temperature orthogonal to the onshore flow. This is perhaps the simplest situation of fog formation, particularly common along the northeast U.S. coast in summertime. More realistic topography and offshore conditions will then be inserted in three-dimensional simulations, including possibly prescribing localized anomalies in sea surface temperature, upon which fog formation is known to be sensitive.

WORK COMPLETED

The Gayno-Seaman PBL scheme has been implemented in MM5 (Version 2.5). A more detailed radiation parameterization than was originally used in Gayno-Seaman has been coupled with the PBL scheme. Tests in a two-dimensional version of MM5, with idealized initial and boundary conditions, have been performed to evaluate the sensitivity of this scheme to environmental factors such as wind speed, sea-surface temperature gradient, and air temperature. Comparisons among three PBL schemes, Burk-Thompson, Gayno-Seaman, and Blackadar, have been performed.

We have begun additional tests for an observed case in three dimensions. Preliminary comparisons have been made among forecasts produced using the Gayno-Seaman scheme, the Blackadar scheme, and the Burk-Thompson scheme.

RESULTS

The two-dimensional configuration represents an initially steady flow of air over a sea-surface temperature gradient from warm water offshore to cold water nearer the coast. Upstream boundary conditions are far removed from the SST gradient such that the air near the surface reaches thermodynamic equilibrium with the sea-surface. Our tests confirm that the Gayno-Seaman scheme has reasonable sensitivity to environmental factors. Wind speed and the magnitude of the SST difference are among the more important environmental parameters, while the steepness of the SST gradient is less important.

These tests also point to some important differences among the Blackadar, Burk-Thompson, and Gayno-Seaman schemes. In our two-dimensional configuration, the Gayno-Seaman scheme produces less cloud water at the surface than either the Blackadar or Burk-Thompson schemes. Gayno-Seaman is also slower to produce fog. This latter tendency may be more related to some

element of our configuration, as preliminary three-dimensional case studies have shown the ability of Gayno-Seaman to form fog quickly.

The case we have selected for our initial three-dimensional tests was a summertime fog event off the New England coast. This was not a marginal fog event; fog was widespread for several days. This case was chosen for initial 3D tests because severe deficiencies in any of the PBL parameterizations would be likely to be revealed. Simulations with the Burk-Thompson scheme and the Gayno-Seaman scheme produce qualitatively similar results with respect to the distribution of fog (Fig. 1). Both schemes quickly form fog over water, but never form significant fog over land. Observations suggest that fog was observed both over water and over land.

Quantitatively, the amount of cloud water formed in the two schemes differs greatly. Burk-Thompson produces in excess of 1.5 g/kg of cloud water, while Gayno-Seaman produces up to about 0.5 g/kg. Observations taken in heavy fog situations near Scotland (Findlater et al., 1989) show cloud-water mixing ratios of up to about 0.5 g/kg. These observations lead us to believe that far too much cloud water is produced by Burk-Thompson and Blackadar, and that even the lesser amounts produced by Gayno-Seaman are probably too large.

IMPACT

The proper selection and tuning of the PBL parameterization are critical for effective numerical forecasts of coastal fog. The inclusion of TKE prediction and partial-fog parameterization in the Gayno-Seaman scheme has a favorable effect on the fog prediction, reducing the very heavy fog (in excess of 1.0 g/kg liquid water using Blackadar, and even more in Burk-Thompson) to something a little lighter (.4 g/kg using Gayno-Seaman).

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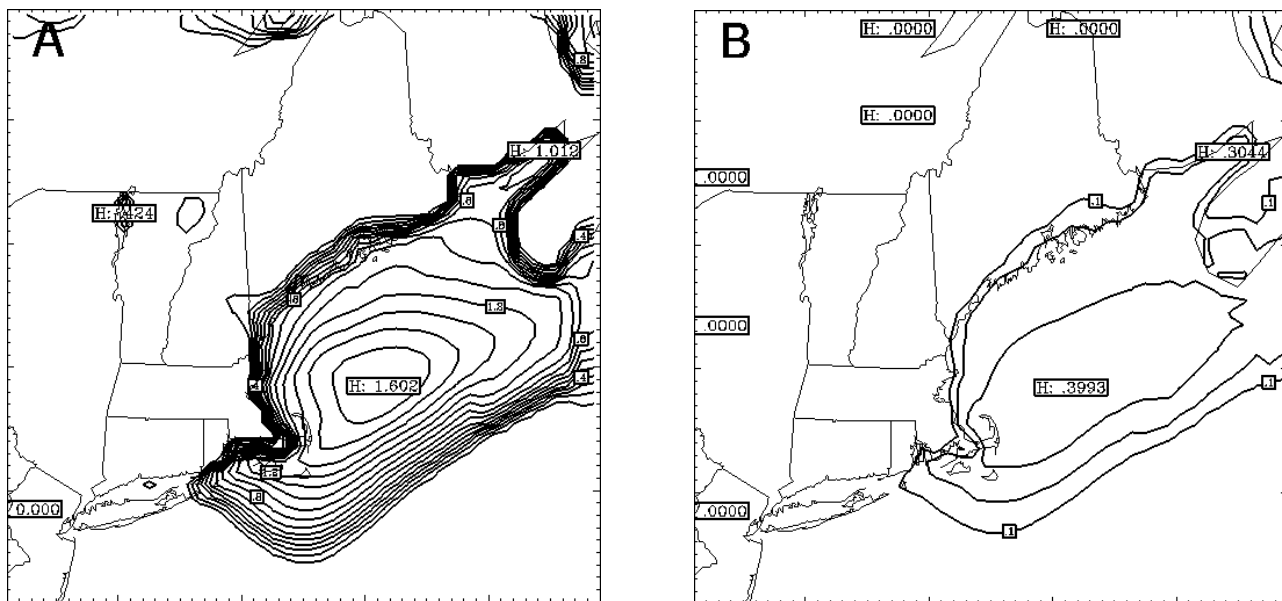


Fig. 1. Six-hour simulations of a coastal fog event, valid at 06 UTC, 27 July 1995. Cloud liquid water content (g/kg) contoured with contour interval of 0.1 g/kg. (A) Simulation with Burk-Thompson PBL. (B) Simulation with Gayno-Seaman PBL.